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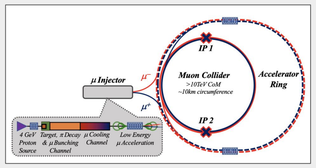
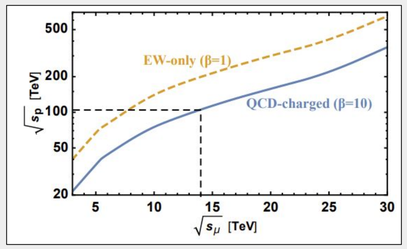
Jet Reconstruction at the Muon Collider: SoftKilling the Beam-Induced Background

Statement of Interest: We apply SoftKiller to the Muon Collider calorimeter to mitigate beam-induced background (BIB), enabling accurate jet reconstruction in a high-noise environment. This study demonstrates that SoftKiller significantly reduces calorimeter contamination, improving jet response and opening the door to precision boosted object measurements at a future muon collider.

A Muon Collider

Muon colliders combine the clean collisions of electron machines with the energy reach of hadron colliders. Thanks to the muon's high mass, **these compact circular colliders can reach multi-TeV energies with minimal synchrotron radiation**.





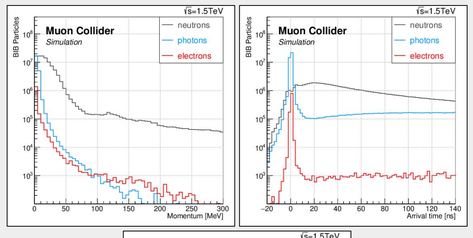
Source: https://arxiv.org/pdf/2303.08533

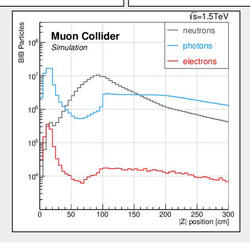
Unlike protons, muons are fundamental, delivering full beam energy into each collision—**ideal for precision Higgs studies** and new physics searches.

Beam-Induced Background (BIB)

Muon decay in the collider ring produces showers of secondary particles that fill the detector with background noise.

This **Beam-Induced Background (BIB) can overwhelm signal events by orders of magnitude**.





As shown to the right, BIB particles tend to:

- Have *low momentum*
- *Arrive late* relative to signal
- *Originate far* from the interaction point

These characteristics offer **handles for separating BIB from signal** before and during reconstruction.

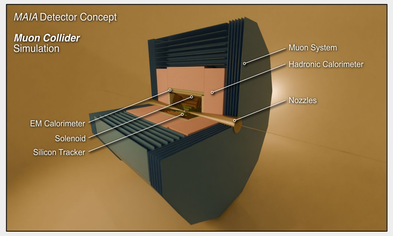
Combining approaches is crucial to reduce the impact of the BIB and achieve precision physics at the muon collider.

Source: https://arxiv.org/pdf/2303.08533

MAIA Detector

The **MAIA** Detector is one of the leading proposed detector concepts for the Muon Collider. It places the calorimeters on the outside of the solenoid. It was originally based on the CLIC design.

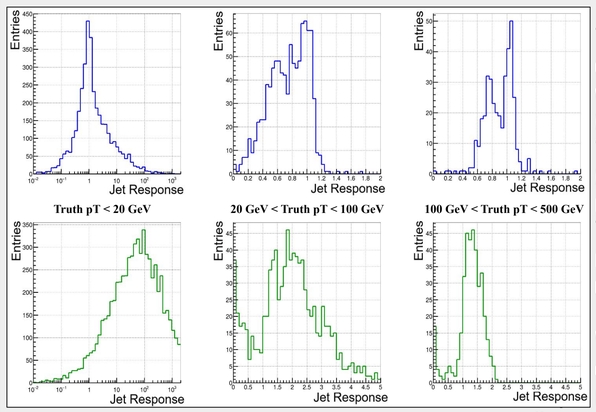
ECAL: *50 Layers of Silicon-Tungsten*
HCAL: *75 Layers of Iron-Scintillator*



Source: https://arxiv.org/abs/2502.00181

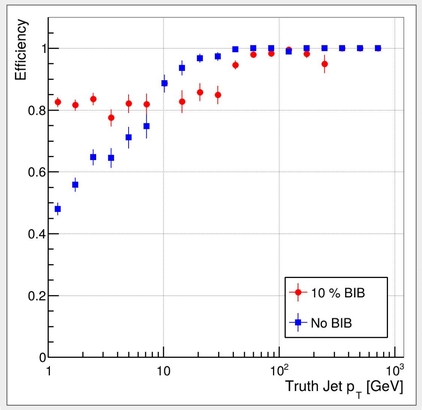
Reconstructing Jets

Jet response, defined as the ratio of truth jet pT to reconstructed jet pT, with truth jets matched to reconstructed jets by minimizing ΔR, can be used to evaluate performance.



To the left, the MAIA detector performs well **without BIB (top)**. But **with 10% BIB (bottom)**, the response degrades. This makes reconstruction unreliable.

We also use **jet efficiency**, the (binned in pT) that are successfully reconstructed. The plot on the left shows high efficiency without BIB.



The plot also shows an *apparent* increase in efficiency with BIB, which might seem positive—however, top plot reveals that many of these reconstructed jets are inaccurate, indicating that the **efficiency gained is driven by background**, not true signal.

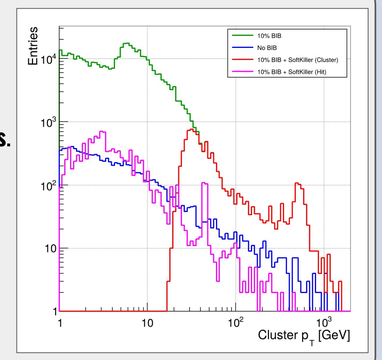
The BIB must be mitigated if any precision analysis is to be done with jets.

SoftKiller

SoftKiller, a pileup mitigation algorithm used at the LHC. Since BIB shares similar features with pileup, **SoftKiller is a natural candidate for muon collider applications.**

Applying it to both *clusters* and *calorimeter hits*, we found **better performance at the hit level**.

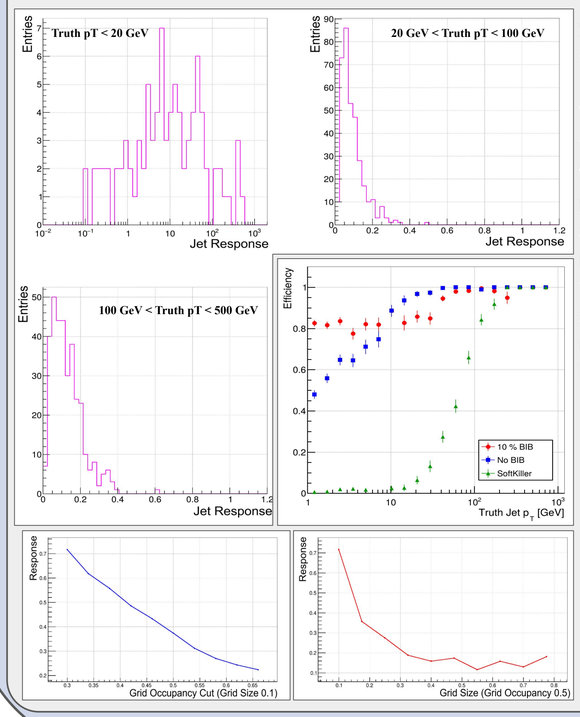
This is illustrated in the cluster pT distributions for 10% BIB (green), no BIB (blue), and SoftKiller applied to (a) *clusters* (red) and (b) *calorimeter hits* (pink).



Mitigating the BIB

The figure below shows that applying SoftKiller with a grid size of 0.4 can **bring the response back down** to acceptable levels—in fact, **it over kills the event**.

The efficiency plot shows that **efficiency remains intact only above 100 GeV**.



SoftKiller allows tuning of the *grid occupancy* and *size*. The bottom plot shows that **reducing the threshold (left) and grid size (right) achieves the best response**. Tuning these parameters, we aim to improve low pT efficiency needed for Higgs physics.

Next Steps

- **Truth-level matching** to validate SoftKiller.
- **Calibrate jets** using response.
- **Higher BIB levels** beyond 10%.